RECONSTRUCTION OF THE 2011/2012 STEELHEAD SPAWNING RUN INTO THE SNAKE RIVER BASIN

Timothy Copeland, Idaho Department of Fish and Game, Nampa, Idaho
Joseph D. Bumgarner, Washington Department of Fish and Wildlife, Dayton, Washington
Alan Byrne, Idaho Department of Fish and Game, Boise, Idaho
Lytle Denny, Shoshone Bannock Tribes, Fort Hall, Idaho
J. Lance Hebdon, Idaho Department of Fish and Game, Boise, Idaho
McLain Johnson, Nez Perce Tribe, Orofino, Idaho
Christopher A. Peery, US Fish and Wildlife Service, Ahsahka, Idaho
Stuart Rosenberger, Idaho Power Company, Boise, Idaho
Edwin R. Sedell, Oregon Department of Fish and Wildlife, La Grande, Oregon
Gene E. Shippentower, Confederated Tribes of the Umatilla Indian Reservation, Pendleton, Oregon
Carl Stiefel, Idaho Department of Fish and Game, Nampa, Idaho
Steven P. Yundt, US Fish and Wildlife Service, Boise, Idaho

FOREWORD AND ACKNOWLEDGEMENTS

Reconstruction of steelhead runs into the Snake River was identified as a key part of the Anadromous Salmonid Monitoring Strategy developed for the Columbia River basin by the management agencies in 2009. The co-managers who developed the Snake River subbasin strategy were Idaho Department of Fish and Game, Nez Perce Tribe, Oregon Department of Fish and Wildlife, Confederated Tribes of the Umatilla Indian Reservation, Washington Department of Fish and Wildlife, and Shoshone-Bannock Tribes. The run reconstruction objective was developed into a proposal by the Nez Perce Tribe and Idaho Department of Fish and Game and approved for funding by Bonneville Power Administration in 2011. In 2012, an interagency workgroup was convened comprised of representatives of the agencies above and two other entities that operate steelhead hatcheries in the Snake basin: the US Fish and Wildlife Service (through the Lower Snake River Compensation Plan office) and the Idaho Power Company. The report that follows is a joint product of the workgroup under the technical lead of Timothy Copeland. Order of the co-authors is alphabetical. The authors would like to acknowledge the constructive reviews from Mike Ackerman and Bill Schrader (Idaho Department of Fish and Game).

Suggested citation:

Copeland, T., J. D. Bumgarner, A. Byrne, L. Denny, J. L. Hebdon, M. Johnson, C. A. Peery, S. Rosenberger, E. R. Sedell, G. E. Shippentower, C. Stiefel, and S. P. Yundt. 2014. Reconstruction of the 2011/2012 steelhead spawning run into the Snake River basin. Report to Bonneville Power Administration, Portland, Oregon.

ABBREVIATIONS AND ACRONYMS

BON	Bonneville Dam
BPA	Bonneville Power Administration
CTUIR	Confederated Tribes of the Umatilla Indian Reservation
CWT	Coded Wire Tag
EF	East Fork
ESA	Endangered Species Act
ESU	Evolutionarily Significant Unit
GIS	Geographic Information System
GSI	Genetic Stock Identification
ICH	Ice Harbor Dam
ICBTRT	Interior Columbia Basin Technical Recovery Team
IDFG	Idaho Department of Fish and Game
LGR	Lower Granite Dam
LS	Little Salmon River
LSRCP	Lower Snake River Compensation Plan
MCN	McNary Dam
MF	Middle Fork
MPG	Major Population Group
NF	North Fork
NPT	Nez Perce Tribe
NOAA	National Oceanic and Atmospheric Administration
ODFW	Oregon Department of Fish and Wildlife
PBT	Parentage Based Tagging
PIT	Passive Integrated Transponder
PTAGIS	PIT Tag Information System
QCI	Quantitative Consultants, Inc.
SBT	Shoshone Bannock Tribes
SF	South Fork
TUC	Tucannon River
WB	Whitebird Creek
WDFW	Washington Department of Fish and Wildlife

TABLE OF CONTENTS

Page

LIST OF TABLES

Page

LIST OF FIGURES

Page

ABSTRACT

Steelhead trout in the Snake River basin are the focus of a variety of harvest and conservation programs. A run reconstruction model offers a systematic way to address information needs for management within the large and complex arena presented by Snake River steelhead. The purpose of this work is to summarize data describing the abundance of steelhead crossing Lower Granite Dam, the spatial distribution of spawning fish, and known fates/disposition. To achieve this, a group was convened of representatives from the anadromous fishery management agencies within the Snake River basin. The immediate objective was to estimate the disposition of the 2011-2012 return of steelhead within the Snake River basin. We estimated 146,264 adipose-clipped hatchery fish, 11,355 unmarked hatchery fish, and 44,750 wild steelhead entered the Snake River during the run (July 1, 2011 to June 30, 2012). Fishery-related mortality in the Snake River basin totaled 97,302 marked hatchery fish, 502 unmarked hatchery fish, and 1,511 wild steelhead. Further, 19,543 marked hatchery fish, 1,659 unmarked hatchery fish, and 72 wild fish were removed at weirs. Another 20 unclipped and 103 clipped hatchery fish were estimated to leave the Snake River to enter the Walla Walla River. Potential spawners remaining in the habitat totaled 30,494 marked hatchery fish, 8,495 unmarked hatchery fish, and 36,296 wild steelhead. Using the run reconstruction model, we attempted to quantify the fishery-related impacts on steelhead as they migrate to their natal or release area, and highlighted the benefits of hatchery programs. This useful framework also allows inferences regarding spatial distribution of spawners and disposition. Comparison with independent data suggested that the model provides realistic estimates for hatchery fish, but methodology for natural fish estimates needs refinement. We have developed a tool for comparative use by steelhead managers in the Snake River basin. This work provides a useful framework for synthesizing data collected by fisheries managers that allows inferences regarding disposition and spatial distribution of spawning fish. The run reconstruction process is a good arena for critical review of the data that managers in the basin use. The model can be used to bridge gaps in the existing data using reasonable assumptions in a structured manner. The resulting output will help evaluate the performance of the Snake River steelhead evolutionarily significant unit (ESU) and hatchery programs towards management goals and ESA delisting criteria. Future improvements will improve precision and accuracy.

INTRODUCTION

Steelhead trout *Oncorhynchus mykiss* in the Snake River basin are the focus of a variety of harvest and conservation programs. Wild populations are listed as threatened under the Endangered Species Act (ESA) while hatchery programs support extensive fisheries as well as a few efforts to supplement wild production. Therefore, steelhead management in the Snake basin is complex and requires information to describe performance of hatchery stocks as well as impacts to the wild populations that co-exist with the hatchery programs.

Historically, the Snake River basin is believed to have supported more than half of the total steelhead production in the Columbia River basin (Mallet 1974). While this is still the case (Fryer et al. 2012), the bulk of the returns to the Snake River basin in recent years are hatchery fish (e.g., Schrader et al. 2012, 2013). Currently, the progeny of 10 hatchery stocks are released within the basin and there are also 24 extant populations of wild steelhead, which are partitioned into five major groups (Table 1). Most of these fish return to areas upstream of Lower Granite Dam, except for one wild population and two hatchery stocks that return to reaches downstream of Lower Granite Dam. The location of Lower Granite Dam facilitates an accounting of the aggregate run prior to the fish encountering the extensive fisheries upstream of the dam. There are also fisheries from the mouth of the Snake River to Lower Granite Dam that impact all Snake River steelhead populations. Additionally, most wild populations spawn during the spring run-off and thus there is little information on spawning escapement (Busby et al. 1996; ICBTRT 2003).

A run reconstruction model (Starr and Hilborn 1988; Chasco et al. 2007) offers a systematic way to address information needs for management within the large and complex arena presented by Snake River steelhead. Most frequently, run reconstruction models synthesize abundance, catch, and migration rates to recursively estimate abundance at points downstream of the terminal area (Quinn and Deriso 1999). Run reconstruction models are capable of incorporating spatial and temporal complexity, given that sufficient data are available.

The purpose of this work is to summarize data describing the abundance of steelhead returning to the Snake River basin, the spatial distribution of spawning fish, and known fates/disposition. This information will help evaluate the performance of the Snake River steelhead evolutionarily significant unit (ESU) and associated hatchery programs towards management goals and ESA delisting criteria. To that end, a group was convened of representatives from the anadromous fishery management agencies within the Snake River basin. The immediate objective was to estimate the disposition of the 2011-2012 return of steelhead within the Snake River basin. We caution the reader that the results presented here are preliminary and should be interpreted with care.

Table 1. List of wild populations and hatchery brood stocks of steelhead spawning in the Snake River basin during 2012 by major population group (MPG). Hatchery stocks are listed by MPG of release with an abbreviation given parentheses.

Wild population	Hatchery brood stock
Lower Snake	
Tucannon River	Lyons Ferry (LF)
Asotin Creek	Tucannon endemic (TEH)
Grande Ronde River	
Lower Grande Ronde	Wallowa (WLH)
Joseph Creek	
Wallowa River	
Upper Grande Ronde	
Imnaha River	
Imnaha River	Imnaha (IMH)
Clearwater River	
Lower Mainstem Clearwater River	Dworshak (DWR)
South Fork Clearwater River	
Lolo Creek	
Selway River	
Lochsa River	
Salmon River	
Little Salmon River	East Fork natural (EFN)
South Fork Salmon River	Oxbow (OX)
Secesh River	Dworshak (DWR)
Chamberlain Creek	Pahsimeroi (PAH)
Lower Middle Fork Salmon River	Sawtooth (SAW)
Upper Middle Fork Salmon River	Upper Salmon B (USB)
Panther Creek	
North Fork Salmon River	
Lemhi River	
Pahsimeroi River	
East Fork Salmon River	
Upper Mainstem Salmon River	
Hells Canyon	
Hells Canyon (extirpated)	Oxbow (OX)

METHODS

Study area

The study area is the portion of the Snake River basin that is currently accessible to anadromous fish. The Snake River is the largest tributary to the Columbia River and has its confluence with the Columbia 522 km upstream of the Pacific Ocean and 288 km upstream of Bonneville Dam, the first dam returning steelhead ascend after leaving the ocean (Figure 1). The last dam steelhead cross before reaching the Snake River is McNary Dam, 52 km downstream of the mouth of the Snake. Within the Snake River, the first dam encountered by adult steelhead is Ice Harbor Dam (river km 16). Lower Granite Dam, the last dam steelhead may cross, is at rkm 173. Fish passage within main stem corridors is blocked at Dworshak Dam (rkm 3 on the North Fork Clearwater River) and at Hells Canyon Dam on the Snake River (rkm 397).

Figure 1. Portions of the Snake River basin accessible to adult steelhead (dark gray) and selected features of the migration route within the Columbia River basin.

Steelhead populations are widely distributed within the Snake River basin (Figure 2). Approximately 97% of the currently accessible spawning habitat is located upstream of Lower Granite Dam (Tom Cooney, NOAA Fisheries, unpublished data). In general, major population groups (MPGs) are delineated by major drainage (Clearwater, Grande Ronde, Imnaha, and Salmon rivers). The Tucannon River population (downstream of Lower Granite Dam) and the Asotin Creek population (upstream of Lower Granite Dam) comprise the Lower Snake MPG. The population within the minor tributaries of the Snake River in Hells Canyon (upstream of the Imnaha River) is considered to be functionally extirpated (Ford et al. 2010). Hatchery fish are released at multiple locations (Figure 3). In general, most hatchery fish are marked by an adipose fin clip (hereafter clipped) and are vulnerable to recreational fisheries within and downstream of the Snake River basin. In order to bolster natural production as mandated by the *US v. Oregon* agreement, some unclipped hatchery fish are released in the Tucannon River, Lolo Creek, South Fork Clearwater River, Little Salmon River, East Fork Salmon River, Yankee Fork Salmon River, and at the Sawtooth Hatchery weir in the headwaters of the Salmon River.

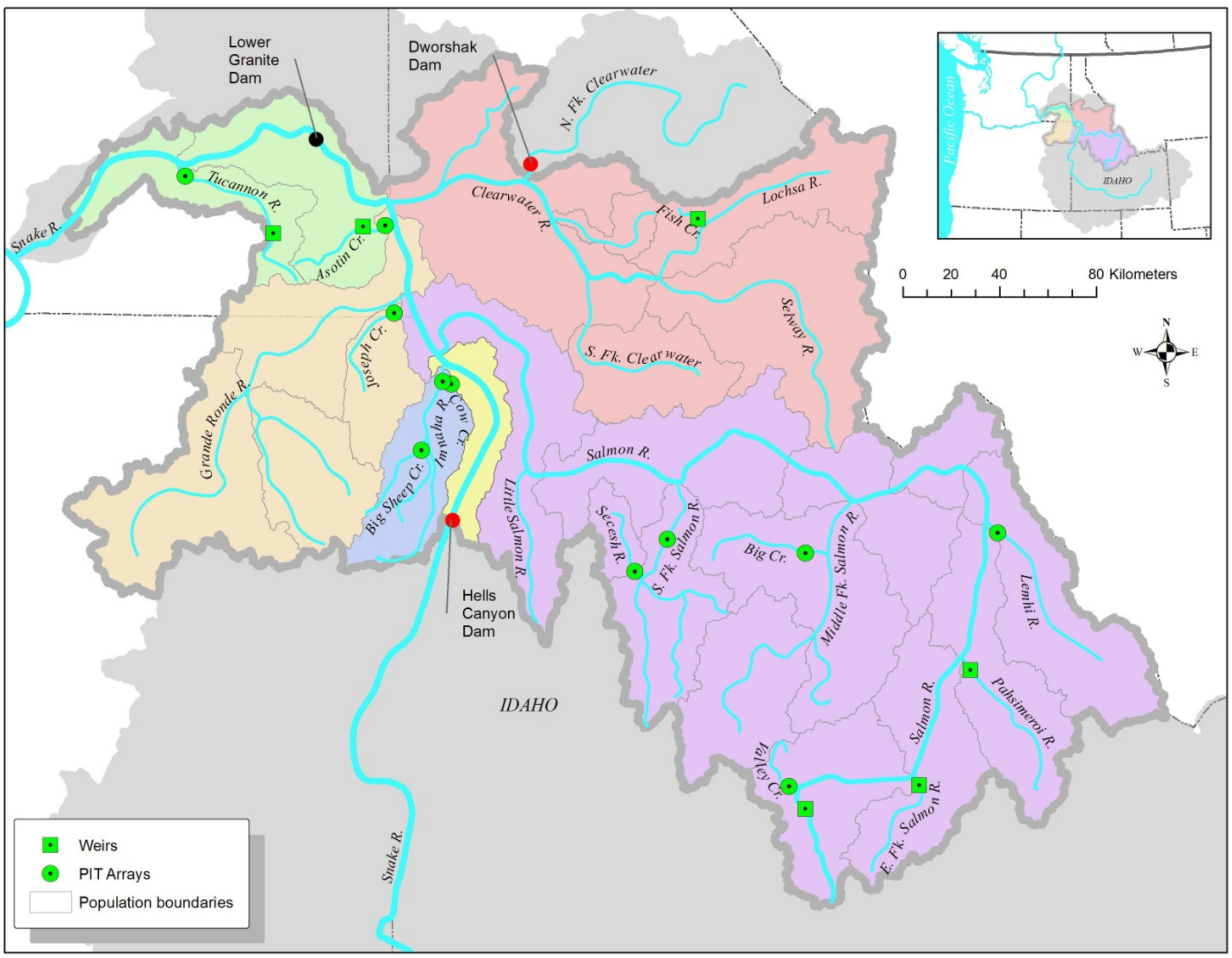

Figure 2. Snake River steelhead populations with locations of selected weirs and PIT tag antenna arrays. Major population groups are denoted by different colors.

Steelhead fisheries within the bounds of the Snake River basin are complex (Figure 3). Recreational fisheries are prosecuted within the main stems of large rivers with harvest beginning in September and continuing into April, although the open and closure dates may vary in some river sections. Angling gear with barbless hooks is permitted and only clipped steelhead may be retained. Tribal fisheries are more limited in spatial extent but employ a variety of gears and retention of unclipped steelhead is allowed. The Nez Perce Tribe operates a commercial gill net fishery in the Snake River between Lower Granite Dam and Hells Canyon Dam and in the main-stem Clearwater River with most effort in the Lower Granite pool. Nez Perce tribal members also pursue subsistence steelhead fisheries throughout the Clearwater River basin, with most effort in the North Fork and South Fork Clearwater rivers. Members of the Confederated Tribes of the Umatilla Indian Reservation pursue subsistence steelhead fisheries with most effort concentrated in the upper Grande Ronde River. Lastly, members of the Shoshone Bannock Tribes harvest steelhead throughout the Salmon River basin with most effort in the Yankee Fork and East Fork Salmon River.

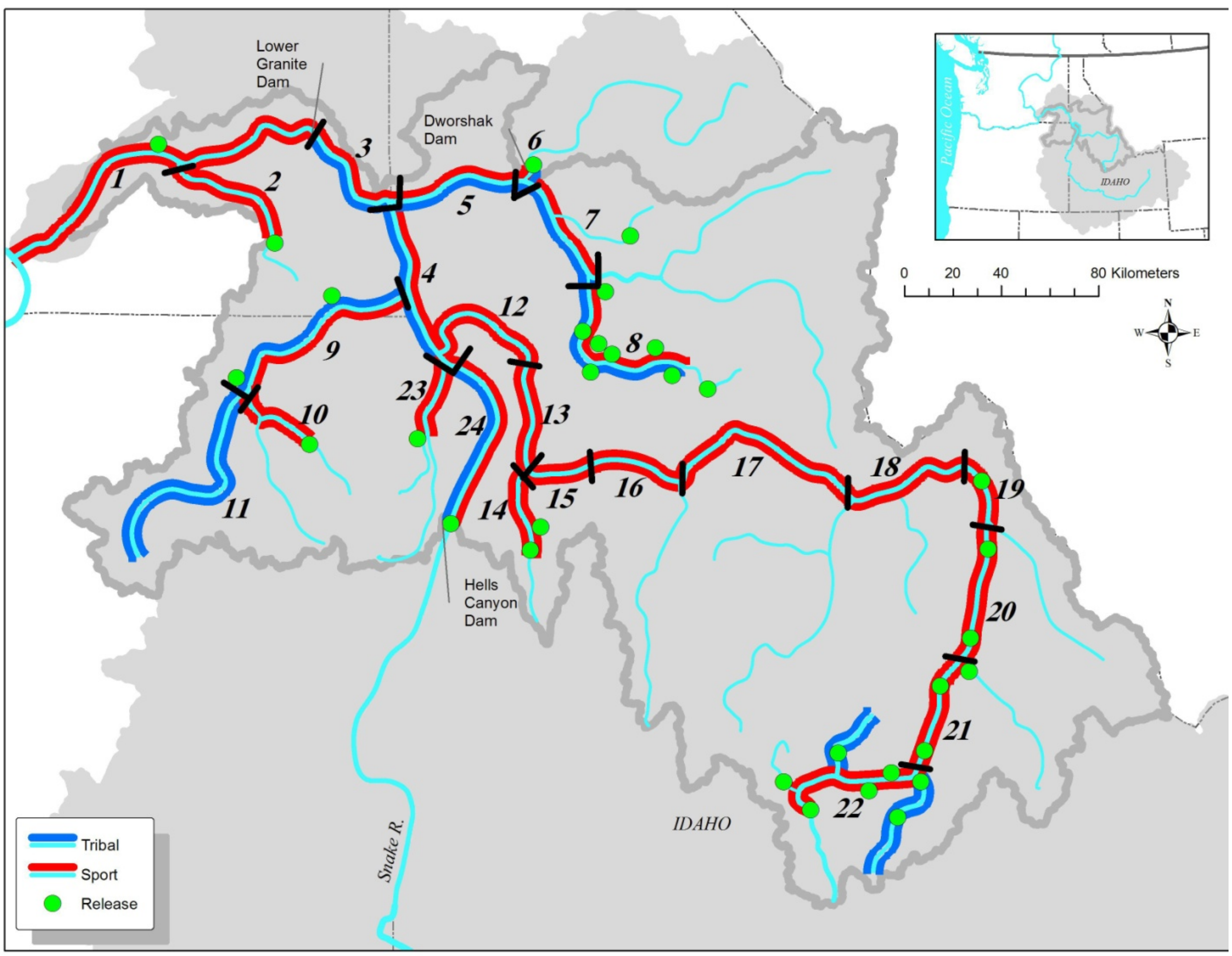

Figure 3. Location of hatchery steelhead release locations and boundaries of harvest reaches within the Snake River basin. Numbers represent the reaches represented as the smallest strata in the run reconstruction model. See Table 2 for reach descriptions.

Model development

We constructed a run reconstruction model with an input vector of abundances and transition matrices composed of survival and movement probabilities. The input vector was based on group abundances at Lower Granite Dam because of the intensive sampling program operating on adult steelhead there (Schrader et al. 2012, 2013). Disposition of these fish within the Snake River basin was estimated recursively by applying survival and movement probabilities. We estimated escapement and loss to fisheries between Ice Harbor Dam and Lower Granite Dam by moving fish backward to Ice Harbor Dam and then applying fisheries losses within that reach. We estimated escapement and losses upstream of Lower Granite Dam by moving fish forward. We also estimated the number of steelhead migrating across Bonneville Dam, although we were unable to separate fishery impacts within the Columbia River from straying and natural mortality.

Formally, we modified the 'box-car' model developed by Starr and Hilborn (1988):

$$N_i = \sum_{j=1}^{r} \left(C_{ij} + E_{ij} \right) \quad (1)$$

where N_i = abundance of stock i at LGR (Table 3),
C_{ij} = catch of stock i in reach j,
E_{ij} = survivors of stock i that remain in reach j after the fishery has occurred,
r = number of reaches stock *i* enters.

Catch of stock *i* in reach *j* is assumed to be in proportion to their abundance in the reach:

$$C_{ij} = C_j * \left(N_{ij} \Big/ \sum_{i=1}^{s} N_{ij} \right) \quad (2)$$

where C_j = total catch in reach j,
N_{ij} = abundance of stock i entering reach j,
s = number of stocks in reach j.

After fishery mortality occurs, fish of stock *i* move to the next reach upstream as:

$$N_{i,j+1} = p_{i,jk} * (N_{ij} - C_{ij}) \quad (3)$$

where $N_{i,j-1}$ = abundance of stock *i* that move from reach *j* into reach *j+1,*
$p_{i,jk}$ = probability of stock *i* moving from reach *j* to reach *k.*

Escapement of stock i in reach j is then:

$$E_{ij} = N_{ij} - N_{i,j+1} - C_{ij}. \quad (4)$$

Within each reach we estimate the number of fish of each stock *i* that were caught (C_{ij}); moved to the next reach ($N_{i,j+1}$); or remained in the reach (*Eij*).The basic concept is that these equations are iterated in each consecutive reach starting downstream and proceeding upstream towards the release reach for hatchery fish and the natal reach for wild populations. Below, we will describe how this concept has been altered in the actual application.

The total abundance of steelhead crossing Lower Granite Dam from July 1, 2011 to June 30, 2012 was based on the expanded window count (see Schrader et al. 2013 for methodology). Schrader et al. (*in prep*.) first partitioned the window count into clipped hatchery fish, unclipped hatchery fish, and wild fish. We further parsed abundance of clipped and unclipped hatchery fish to release location based on expansion of PIT tag detections at Lower Granite Dam. Release locations were aggregated within fisheries reaches (see Figure 3) to simplify accounting within the model. Schrader et al. (*in prep*.) parsed abundance of wild fish into genetic stocks established by Ackerman et al. (2012) using genetic stock identification (GSI) on adult steelhead sampled at Lower Granite Dam. Genetic stocks are larger than the populations, so we further parsed them into populations based on the spawning area weighted by intrinsic potential of the currently occupied streams from the most recent ESA status assessment (Ford et al. 2010). Based on genetic structure and assignment tests, Lolo Creek was aligned with the South Fork Clearwater genetic group and Chamberlain Creek with the Middle Fork Salmon group (Mike Ackerman, personal communication).

We made two adjustments to the abundance estimates based on the dam count. First, we found previously that abundance of Lower Snake stocks (Tucannon and Asotin populations) appeared biased high (Copeland et al. 2013). We used PIT tag detections to estimate the rate at which steelhead had been double counted at Lower Granite Dam. The re-ascension rate was calculated by dividing the number of re-ascension events by number of unique adult PIT tags detected at Lower Granite Dam. This was very different for stocks originating upstream versus downstream of the dam, so we applied two different rates. Further, the total dam count is biased low because some fish pass outside of counting hours (Dauble and Mueller 2000; Boggs et al. 2004). So to be as complete as possible with the available data, we used the proportion of PIT tags passing during night-time hours to adjust the total window count upward for all stocks.

We used 24 river reaches to define sport fisheries to delineate the spatial detail of the run reconstruction mode (Figure 3, Table 2). Total fishery mortality in each reach was the sum of harvest and incidental catch-and-release mortality. Unless otherwise specified, we assumed that 5% of the fish that were caught and released eventually died (WDFW 2009). Catch and harvest statistics were based on data collected by in-season creel surveys except those provided by Idaho Department of Fish and Game (IDFG) and Washington Department of Fish and Wildlife (WDFW). IDFG estimated catch and harvest data with a post-season phone survey (Petrosky 2012). Take of wild fish by sport fisheries in Idaho was estimated statewide based on the encounter rate of hatchery fish. We parsed the statewide take of unclipped steelhead into the Idaho fishery reaches based on proportion of the reported unclipped steelhead catch in each reach. WDFW used harvest estimates derived from angler returns of catch record cards. Take of wild steelhead by sport fisheries in the main-stem Snake River in Washington was estimated from creel survey encounter rates and assuming 5% mortality. Total take was then parsed into the appropriate fishery reaches. The fisheries data for northeast Oregon were unavailable for 2011-2012, so we used 2009-2010 data (Flesher et al. 2012) scaled to the 2011-2012 escapement at Lower Granite Dam. Likewise, 2011-2012 fishery data were unavailable for the Shoshone Bannock Tribes, so we used 2008-2009 data (Brandt 2009).

We modeled upstream movement assuming wild fish returned to where they were spawned (based on genetic stock assignment) and that hatchery fish returned to their smolt release location. Therefore, fish moved with $p_{i,k\text{-}j}$=1.0 if reach k was not the point of origin. Where a wild population extended over more than one reach, we used the weighted intrinsic potential spawning area (ICBTRT 2007) within the reach as a proportion of the population total to define probability of upstream movement and reach residence. Hatchery fish returned to a point of release; therefore, all release points within a reach were combined. Specific fishery reach definitions and their resident stocks are given in Table 2. Stocks that return to tributaries within a fishery reach are treated as residents (E_{ij}) of that reach, i.e., they escape to their spawning area without further mortality. Other modifications of movement probabilities and their bases are given below.

Table 2. Description of fishery reaches in the Snake River basin, including agencies reporting fisheries within them during 2011-2012, and stocking reaches for hatchery stocks. Hatchery stocks are listed by release site with stock abbreviation in parentheses. Abbreviations are given in Table 1. Unclipped hatchery releases are denoted by ^{u} and clipped releases by ^{c}. Reach numbers correspond to those in Figure 3. Wild population names are underlined.

Reach	Agencies	Resident wild and hatchery stocks
Snake River downstream of Lower Granite Dam		
1. Ice Harbor-Lower Granite	WDFW	Tucannon, Snake(LF^{c})
Tucannon River		
2. Mouth to Tucannon Fish Hatchery	WDFW	Tucannon, Tucannon(TEH^{u},LF^{c})
Snake River upstream from Lower Granite Dam		
3. Lower Granite to Clearwater River	WDFW, NPT	Asotin
4. Clearwater to Salmon/Imnaha	WDFW, IDFG	Asotin
24. Salmon/Imnaha to Hells Canyon Dam	IDFG	Snake(OX^{c})
Clearwater River		
5. Mouth to Orofino	IDFG, NPT	Lower Clearwater
6. North Fork Clearwater	IDFG, NPT	NF Clearwater(DWR^{c})
7.Orofino to Clear Creek	IDFG, NPT	Lower Clearwater, Lolo, Lolo(DWR^{u}), Clear Creek(DWR^{c}), Lochsa, Selway
8. South Fork Clearwater	IDFG, NPT	South Fork Clearwater, SF Clearwater(DWR^{u,c})
Grande Ronde River		
9. Mouth to Wallowa River	WDFW, ODFW	Lower Grande Ronde, Joseph Creek, Cottonwood(WLH$^{c)}$
10. Wallowa River	ODFW	Wallowa, Wallowa(WLH^{c})
11. Upstream of Wallowa River	CTUIR	Upper Grande Ronde
Imnaha River		
23. Mouth upstream	ODFW	Imnaha, Imnaha(IMH^{c})
Salmon River		
12. Mouth to Whitebird Creek	IDFG	Little Salmon
13. Whitebird to Little Salmon mouth	IDFG	Little Salmon
14. Little Salmon River upstream	IDFG	Little Salmon, Ltl Salmon(PAH^{u,c},OX^{c},DWR^{c})
15. Little Salmon to Vinegar Creek	IDFG	NA
16. Vinegar to South Fork	IDFG	South Fork Salmon, Secesh, Chamberlain
17. South Fork to Middle Fork	IDFG	Chamberlain, Lower Middle Fork, Upper Middle Fork, Panther
18. Middle Fork to North Fork	IDFG	Panther, North Fork Salmon
19. North Fork to Lemhi	IDFG	Lemhi, Salmon sec 19(PAH^{c})
20. Lemhi to Pahsimeroi	IDFG	Pahsimeroi, Salmon sec 20(USB^{u},PAH^{c})
21. Pahsimeroi River to East Fork	IDFG, SBT	East Fork, Salmon sec 21(EFN^{u},SAW^{c},DWR^{c})
22. East Fork upstream	IDFG, SBT	Upper Salmon, Salmon sec 22(SAW^{u,c},DWR^{c},USB^{c})

We used PIT tag detections within the hydrosystem to estimate conversion of stocks from Bonneville Dam to the study area (measured at Ice Harbor Dam) and from Ice Harbor Dam to Lower Granite Dam. Losses downstream of Lower Granite Dam (as far as Bonneville Dam) were estimated using PIT tag detections at main-stem dams and in the lower Tucannon River. The PTAGIS database (www.ptagis.org) was queried for adult detections (between 20 June 2011 and 31 December 2011) at Bonneville Dam of fish tagged as juveniles in the Snake River basin. Conversion rates were the proportion of PIT-tagged fish detected at a dam that were later detected at any upstream dam. We computed conversion rates by origin type (hatchery versus wild) and area of release (4^{th} field hydrologic unit code). Conversion rates were calculated based on detections at Bonneville, McNary, Ice Harbor, and Lower Granite dams. Using the conversion rates we estimated stock abundance at Ice Harbor, McNary, and Bonneville dams as:

$$N_{id} = {}^{N_i}/_{CR_{id}} \quad (5)$$

where N_i = abundance of stock *i* at LGR,
N_{id} = abundance of stock *i* at dam *d*,
CR_{id} = conversion rate of stock *i* from dam *d* to LGR,
d = Ice Harbor, McNary, Bonneville dams.

Unlike the treatment of movement upstream of Lower Granite Dam, here movement probability is confounded with survival in the conversion rate, so modeled fish are moved before the fishery, because they have survived harvest mortality by definition. However, when reporting losses within the Lower Snake reach, we only give fishery-related losses to maintain comparability to reaches upstream of Lower Granite Dam.

Hatchery and wild stocks from the Lower Snake (downstream of Lower Granite Dam) and Tucannon River are known to stray extensively (Bumgarner and Dedloff 2011); many of them pass their point of origin and cross Lower Granite Dam. Many are thought to remain upstream of Lower Granite Dam while a minority (15%-25%) falls back downstream into the Lower Snake reach. We used PIT tag detections at Ice Harbor Dam, the lower Tucannon River, and Lower Granite Dam to estimate movement probabilities of wild Tucannon fish, Tucannon endemic stock hatchery fish, and Lyons Ferry stock hatchery releases moving from Ice Harbor Dam to the Tucannon River or falling back over Lower Granite Dam into the Tucannon River. Fallback probabilities were applied to fish within Lower Granite pool only. Fallbacks from Lower Granite pool are removed after fishery losses are subtracted and routed to their final destination (Tucannon River) and are not eligible to be harvested downstream of Lower Granite Dam. Figure 4 illustrates dataflow from Lower Granite Dam down to Bonneville Dam and how Lower Snake stocks move within the study area.

Hatchery stocks not resident to the Clearwater River will enter the lower Clearwater River (reach 5) and comprise a significant proportion of the harvest, based on coded wire tag (CWT) recoveries (Stiefel et al. 2013). Likewise, hatchery fish released upstream of the North Fork Clearwater River (reach 6) will enter that reach. We estimated a 'dip-in' rate (p_{dip}) for the lower Clearwater and North Fork Clearwater rivers based on CWT recoveries (from Stiefel et al. 2013). For each major drainage (e.g., Lower Snake, Salmon River):

$$p_{idip} = {}^{H_{ir}}/_{(N_{r-1} * h_i)} \quad (6)$$

where H_{ir} = harvest of stock *i* based on CWT recoveries in the lower Clearwater or the NF Clearwater rivers,
N_{r-1} = abundance of stock *i* in the reach downstream,
r =5 for lower Clearwater and 6 for NF Clearwater,
h = harvest rate of the resident stock (all Clearwater in r=5 or NF Clearwater in r=6).

Harvest rate is computed for the grouped upstream stocks based on the assumptions that all resident fish move with probability 1.0 and that all stocks are harvested in proportion to their abundance. After calculating H_{ir}, surviving fish not bound for the reach in question fall back from the 'dip-n' reach and continue their movement upstream. Figure 5 illustrates dataflow for reaches upstream of Lower Granite Dam, including dip-in steps.

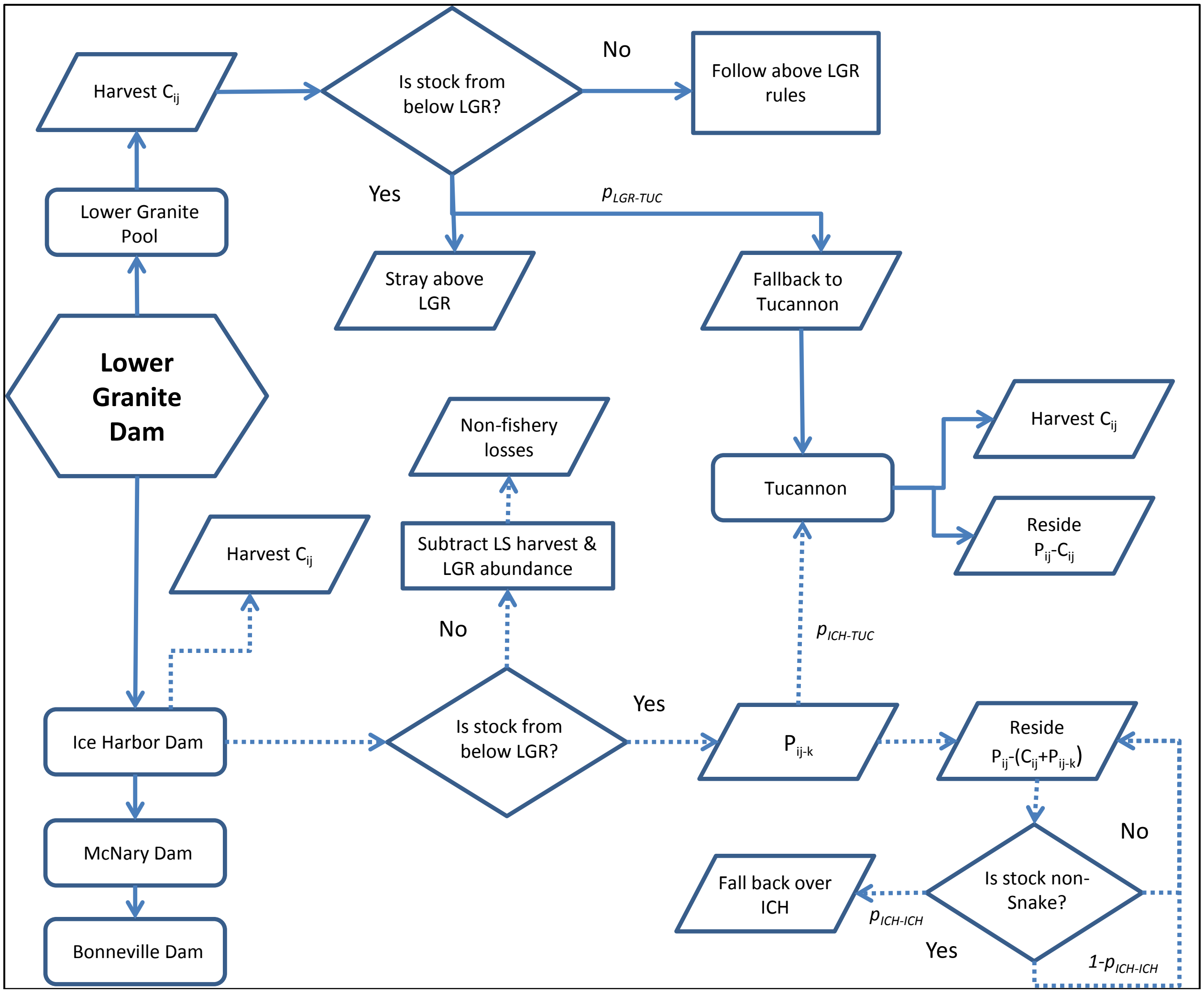

Figure 4. Flowchart for projection of abundance at Lower Granite Dam back to Bonneville Dam and movement of Lower Snake stocks between Ice Harbor Dam and Lower Granite pool.

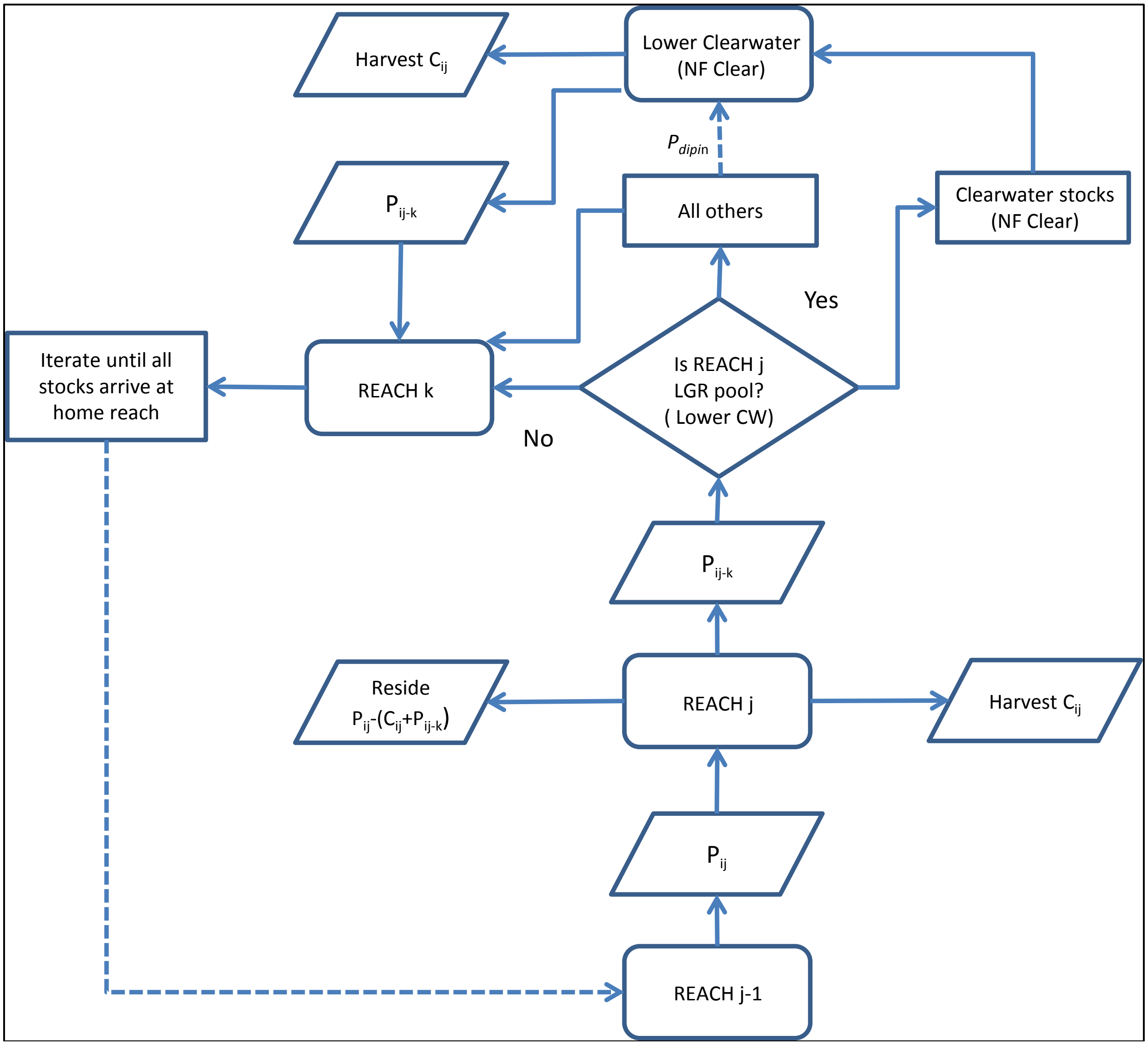

Figure 5. Flowchart for movement and fates of steelhead upstream of Lower Granite Dam. Abbreviations are explained in the text. Dip-in decisions are for non-Clearwater stocks in Lower Granite pool or for upper Clearwater/South Fork Clearwater stocks in the lower Clearwater (in parentheses).

Output of the run reconstruction model is summarized into three categories: abundance at important locations, escapement after fisheries, and abundance of potential spawners. Initial abundance is estimated as number crossing Bonneville Dam. Abundance is also estimated at Ice Harbor Dam, at Lower Granite Dam, and at the mouth of the natal river or terminal reach (except for Lower Snake stocks). Losses between Bonneville and Ice Harbor dams include all mortality sources; losses upstream of Ice Harbor Dam include only fishery-related mortality. Escapement is then the fish that avoid fishery-related mortality, assuming that natural mortality takes place only downstream of Ice Harbor Dam and in the spawning reaches. Fates of fish removed at weirs are known with certitude; therefore, we also report the number of fish that are potentially at-large within spawning reaches. Outputs are tabulated only for Snake River stocks; however, in the text we report mortality and escapement within the study area of non-Snake stocks that were detected at Lower Granite Dam.

RESULTS

Model input data

The preliminary abundance estimates at Lower Granite Dam for the 2011-2012 steelhead run were 130,809 individuals for clipped hatchery fish, 10,007 unclipped hatchery fish, and 39,504 wild fish (Schrader et al., *in prep*.). After incorporating night passage (8.3%) and re-ascensions (35.5% for Lower Snake stocks and 6.2% for all others), the adjusted estimates were 132,292 individuals for clipped hatchery fish, 10,117 unclipped hatchery fish, and 37,433 wild fish (Table 3). Of the 24 hatchery release groups, three were from locations outside of the Snake basin (from the Touchet and Walla Walla rivers). The largest hatchery return group at Lower Granite Dam was from the Salmon River between the Lemhi and Pahsimeroi rivers (reach 20). Other release locations with more than 10,000 adult returns were Salmon River upstream of the East Fork (reach 22), Hells Canyon (reach 24), North Fork Clearwater River (reach 6), and Little Salmon River (reach 14). Most of the unclipped hatchery steelhead were returning to South Fork Clearwater River or the Salmon River upstream of the East Fork. We estimated that the largest wild population was the Tucannon River and the smallest was the Secesh River.

Total fishery-related mortality of clipped hatchery fish within the study area was 99,334 (Table 4). This number includes direct harvest as well as incidental mortality from catch-and-release handling. Incidental take of unclipped steelhead was estimated at 2,032 fish, which includes unclipped hatchery fish as well as wild fish. The largest total losses of clipped hatchery fish were in the lower Clearwater River (reach 5), lower Snake River (reach 1), and the upper Snake River (reach 4). The largest fishery mortality estimates of unclipped fish were in the lower Grande Ronde River (reach 9), lower Snake River (reach 1), and South Fork Clearwater River (reach 8). No harvests or catches were reported in the Wallowa River (reach 10) or upper Grande Ronde River (reach 11).

We estimated conversion rates of all Snake River stocks within the Columbia River hydrosystem based on PIT tag detections (Table 5). Conversion rate from Bonneville to McNary dam averaged 81.5% for wild steelhead and 77.9% for hatchery steelhead. Conversion rates from McNary to Ice Harbor dam averaged 96.3% for wild fish and 96.1% for hatchery fish. Conversion rate from Ice Harbor to Lower Granite dam averaged 89.2% for wild fish and 93.0% for hatchery fish for stocks originating upstream of Lower Granite Dam.

Temporary straying of non-Clearwater steelhead stocks (p_{dip}) into the lower Clearwater River varied widely (Table 6). It was highest for Lower Snake stocks and lowest for Salmon River stocks with the other MPGs closer to the Salmon River estimate. However, Salmon River stocks composed the largest component of dip-ins in absolute numbers because of their greater abundance in Lower Granite pool. The dip-in rate for clipped hatchery fish that were released upstream of the North Fork Clearwater River into the North Fork Clearwater River was 0.0515.

Table 3. Abundance of steelhead at Lower Granite Dam by wild population and hatchery stock derived from genetic stock identification and PIT tag expansions. Hatchery stocks are listed by release site with stock abbreviation in parentheses. Abbreviations are given in Table 1. Unclipped hatchery releases are denoted by [u] and clipped releases by [c]. Asterisks indicate mid-Columbia release locations. Values were adjusted from Schrader et al. (in prep.) to account for fallback, re-ascension, and night passage.

Wild populations		**Hatchery stocks**	
Name	**Abundance**	**Release site (stock)**	**Abundance**
Tucannon	5,129	Walla Walla (LF)[c]*	749
Asotin Creek	3,624	Touchet (endemic)[u]*	17
Lower Grande Ronde	1,148	Touchet (LF)[c]*	694
Wallowa	2,287	Snake(LF)[c]	717
Joseph Creek	836	Tucannon(TEH)[u]	260
Upper Grande Ronde	2,755	Tucannon (LF)[c]	1,300
Lower Clearwater	1,657	Lolo (DWR)[u]	428
Lolo Creek	665	SF Clearwater (DWR)[u]	3,215
South Fork Clearwater	2,338	SF Clearwater (DWR)[c]	8,877
Lochsa	939	NF Clearwater (DWR)[c]	11,302
Selway	1,612	Clear Creek (DWR)[c]	3,629
Little Salmon	1,203	Cottonwood(WLH)[c]	4,144
South Fork Salmon	688	Wallowa (WLH)[c]	8,835
Secesh	294	Little Salmon (PAH)[u]	1,111
Chamberlain Creek	410	Little Salmon (OX,PAH,DWR)[c]	13,797
Lower Middle Fork	1,150	Salmon sec 19 (PAH)[c]	2,134
Upper Middle Fork	1,225	Salmon sec 20 (USB)[u]	157
Panther Creek	521	Salmon sec 20 (PAH)[c]	28,175
North Fork Salmon	298	East Fork Salmon (EFN)[u]	1,938
Lemhi	1,674	Salmon sec 21 (SAW,DWR)[c]	5,165
Pahsimeroi	1,388	Salmon sec 22 (SAW)[u]	2,991
East Fork Salmon	1,477	Salmon sec 22 (SAW,USB,DWR)[c]	22,094
Upper Salmon	1,786	Imnaha (IMH)[c]	3,242
Imnaha	2,329	Snake (OX)[c]	18,413

Table 4. Estimated fishery mortalities by river reach and mark type. Mortality for clipped fish is divided into harvest and catch-and-release mortality.

		Clipped	
River and reach	**Unclipped**	**Harvest**	**Catch-and-Release**
1. Lower Snake	230	9,114	10
2. Tucannon	9	1,650	11
3. Lower Granite Pool	187	5,254	20
4. Upper Snake	138	8,348	33
5. Lower Clearwater	200	13,137	414
6. North Fork Clearwater	144	5,740	45
7. Clearwater to Clear Creek	51	2,976	20
8. South Fork Clearwater	213	6,121	213
9. Lower Grande Ronde	329	6,236	250
10. Wallowa River	0	0	0
11. Upper Grande Ronde	0	0	0
12. Salmon to Whitebird	26	2,531	22
13. Salmon (WB-Little Salmon)	27	3,261	45
14. Little Salmon	37	3,614	69
15. Salmon (LS to Vinegar)	20	3,203	21
16. Salmon (Vinegar to SF)	8	584	6
17. Salmon (SF to MF)	44	2,747	11
18. Salmon (MF to NF)	61	7,743	97
19. Salmon (NF to Lemhi)	16	2,046	25
20. Salmon (Lemhi to Pahsimeroi)	18	2,542	60
21. Salmon (Pahsimeroi to EF)	12	892	53
22. Salmon (EF upstream)	36	2,895	81
23. Imnaha	207	389	14
24. Hells Canyon	19	4,750	9

Table 5. Conversion rates in the hydrosystem for selected reaches, by major population group (HUC4) and rearing type. NA- see Table 7 for stock specific values.

	Reach		
Group and origin	**Bonneville to McNary**	**McNary to Ice Harbor**	**Ice Harbor to Lower Granite**
Lower Snake wild	0.8018	0.9485	NA
Lower Snake hatchery	0.7981	0.9715	NA
Asotin wild	0.8000	0.9583	0.8000
Grande Ronde wild	0.8488	0.9589	0.9194
Grande Ronde hatchery	0.7546	0.9570	0.9161
Imnaha wild	0.8521	0.9587	0.9115
Imnaha hatchery	0.7985	0.9535	0.9233
Clearwater wild	0.8261	0.9561	0.9417
Clearwater hatchery	0.7531	0.9759	0.9398
Hells Canyon hatchery	0.7579	0.9502	0.9289
Salmon wild	0.7600	1.000	0.8864
Salmon hatchery	0.8105	0.9594	0.9421

Table 6. Computation of dip-in rates of clipped non-Clearwater hatchery stocks into the lower Clearwater River (reach 5). Hatchery stocks are grouped by region. Harvest was determined from CWT recoveries (Stiefel et al. 2013).

Stock	Reach 5 harvest	LGR pool abundance	Dip-in rate
Lower Snake	871	3,321	0.6144
Grande Ronde	379	12,462	0.0712
Salmon	1,098	68,520	0.0375
Imnaha	266	3,113	0.2002
Hells Canyon	730	16,743	0.1021
Clearwater	9,757	22,858	--

Steelhead from Lower Snake stocks residing downstream from Lower Granite Dam tend to overshoot their natal reach and pass upstream of Lower Granite Dam, some of which return back downstream (Table 7). Conversion rates from Ice Harbor to Lower Granite dam for the Lyons Ferry stock release groups ranged from 29.1% to 49.0%, while 59.0% of the wild Tucannon fish crossed Lower Granite Dam. Of the Lower Snake fish that crossed Ice Harbor Dam (all stocks and origins), 2.2% to 28.2% were estimated to move directly to the Tucannon River and stay there. By subtraction, 5.0% to 58.7% stayed within the Lower Snake downstream of Lower Granite Dam as either mortalities or escapement. Note that these three probabilities include all possible fates for these stocks between Ice Harbor and Lower Granite dams, i.e., they sum to 1.0. A subset of the Lower Snake stocks ascending Lower Granite Dam (22.2% to 38.9%) fell back over Lower Granite Dam and entered the Tucannon River. A subset of the non-Snake steelhead that remained in the lower Snake River (2.5% to 8.3%) were detected in the Walla Walla basin and considered to have fallen back over Ice Harbor dam after the fishery.

Table 7. Movement probabilities of Lower Snake stocks within the Ice Harbor to Lower Granite reach. Rates are based on PIT tag detections. Hatchery stocks are listed by release site with stock abbreviation in parentheses. Abbreviations are given in Table 1. Unclipped hatchery releases are denoted by ^{u} and clipped releases by ^{c}.

	Movement type				
Population/Stock	**Ascend LGR**	**Enter TUC**	**Die/reside**	**Move LGR-TUC**	**Fallback over ICH**
Tucannon wild	0.5897	0.2821	0.1282	0.3478	0
Tucannon (TEH)^{u}	0.4500	0.5000	0.0500	0.3889	0
Tucannon(LF)^{c}	0.4898	0.1531	0.3571	0.2500	0
Touchet (endemic)^{u}	0.0526	0.1579	0.7106	0	0.0789
Snake (LF)^{c}	0.3913	0.0217	0.5870	0.2222	0
Walla Walla (LF)^{c}	0.2911	0.0253	0.6583	0.1304	0.0253
Touchet (LF)^{c}	0.4167	0.0694	0.4306	0.2333	0.0833

Run reconstruction

We report summaries by major population groups beginning downstream and proceeding upstream along the Snake River. Summaries of hatchery release groups are given next to the wild populations in which they are released.

Lower Snake River

Abundance for stocks from the Lower Snake major population group at Bonneville Dam was 17,346 wild fish; 746 unclipped Tucannon endemic stock; and 5,786 for the two Lyons Ferry clipped hatchery groups (Table 8). Substantial losses occurred before these stocks reached the Snake River (range 19.1% to 24.6%). These fish crossed Lower Granite Dam in large numbers, even stocks that were not from upstream of Lower Granite Dam. Losses within reaches 1 and 2 were 65 wild fish (0.5%), 3 unclipped hatchery fish (0.5%), and 1,408 clipped hatchery fish (31.4%). Losses upstream of Lower Granite Dam (reaches 3 and 4) were 116 wild fish (1.3%), four unclipped hatchery fish (1.5%), and 663 clipped hatchery fish (32.9%). Escapements were greatest for the two wild populations; however, 3,203 hatchery fish also escaped. In addition, several non-Snake release groups raised at Lyons Ferry Hatchery entered the study area. We did not estimate their abundance at Bonneville Dam but did estimate they contributed to fisheries in the Snake River and over 3,100 escaped within the study area.

Final dispositions are known for fish removed at weirs within the Lower Snake major population group (Table 8; J. Bumgarner, unpublished data). There are three weirs in the study area downstream of Lower Granite Dam: Lyons Ferry Hatchery trap, the Almota Creek weir, and the Tucannon Fish Hatchery weir. Of the Lower Snake hatchery stocks, 953 clipped and 217 unclipped fish were removed at these three weirs. Another 20 unclipped and 103 clipped fish were estimated to leave the Lower Snake to enter the Walla Walla River, leaving 480 unclipped and 2,937 clipped steelhead at large downstream of Lower Granite Dam. For the Tucannon population, 39.2% of the potential spawners were hatchery fish. There are four weirs in the Lower Snake major population group upstream of Lower Granite Dam: Alpowa Creek, Asotin Creek, George Creek, and Ten Mile Creek. Of the Lower Snake hatchery stocks, 135 clipped and 49 unclipped fish were removed at these four weirs, leaving 1,597 hatchery fish at large. For the Asotin Creek population (all spawning areas), 18.9% of the potential spawners were hatchery fish.

Clearwater River

Abundance for stocks from the Clearwater major population group at Bonneville Dam was 9,695 wild steelhead; 5,273 unclipped hatchery steelhead; and 34,469 clipped hatchery steelhead (Table 9). Between Bonneville and Ice Harbor dams we estimated that 21.0% of the wild fish and 26.5% of the hatchery fish were lost. Loss rates of wild and unclipped hatchery Clearwater stocks were similar in the Snake River fisheries downstream of and upstream of Lower Granite Dam; however, clipped hatchery releases were more heavily exploited downstream of Lower Granite Dam. Fishery-related losses were greatest within the Clearwater River fisheries for all of these stocks. Losses within the lower Snake River (reach 1) were 31 wild fish (0.4%), 16 unclipped hatchery fish (0.4%), and 1,580 clipped hatchery fish (6.2%). Losses in the Snake River upstream of Lower Granite Dam (reach 3) were 29 wild fish (0.4%), 14 unclipped hatchery fish (0.4%), and 950 clipped hatchery fish (4.0%). Losses within the Clearwater River were 278 wild fish (3.9%), 249 unclipped hatchery fish (6.7%), and 25,208 clipped hatchery fish (110.3%). This left a deficit escapement of clipped fish in the South Fork Clearwater River. Fishery impacts on non-Clearwater stocks in the lower Clearwater River (reach 5) were estimated to be 77 wild fish, four unclipped hatchery fish and 3,458 clipped hatchery fish. The total fishery-related losses within this reach composed of non-Clearwater fish were 49.9%, 8.9%, and 25.5% for wild, unclipped hatchery, and clipped hatchery groups, respectively. We estimated escapement in the Clearwater River was 6,904 wild fish, 3,380 unclipped hatchery fish, and 1,572 clipped hatchery fish. Clipped hatchery fish escaped the fishery only in North Fork Clearwater River and Clear Creek.

Table 8. Reconstruction of wild and hatchery stocks residing in the Lower Snake major population group. Escapement is computed by spawning reach for wild steelhead and release location for hatchery steelhead. Hatchery stocks are listed by release site with stock abbreviation in parentheses. Abbreviations are given in Table 1. Unclipped hatchery releases are denoted by [u] and clipped releases by [c].

	Abundance at:			**Escapement**		**Left to spawn**	
Stock	**BON**	**ICH**	**LGR**	**ICH-LGR**	**Above LGR**	**Below LGR**	**Above LGR**
Tucannon wild	11,437	8,698	5,129	5,301	3,286	5,301	3,286
Tucannon (TEH)[u]	746	578	260	416	155	199	106
Tucannon (LF)[c]	3,423	2,654	1,300	782	561	626	481
Snake (LF)[c]	2,363	1,832	717	961	328	553	317
Asotin wild	5,909	4,530	3,624	0	3,574	0	3,574
Touchet (endemic)[u*]	na	323	17	305	17	281	17
Walla Walla & Touchet (LF)[c]	na	4,238	1,443	2,246	720	1,758	676

Table 9. Reconstruction of wild and hatchery stocks residing in the Clearwater major population group. Escapement is computed by spawning reach for wild steelhead and release location for hatchery steelhead. Hatchery stocks are listed by release site with stock abbreviation in parentheses. Abbreviations are given in Table 1. Unclipped hatchery releases are denoted by [u] and clipped releases by [c].

	Abundance at:					
Stock	**BON**	**ICH**	**LGR**	**Clearwater mouth**	**Escape**	**Left to spawn**
Lower Clearwater wild	2,227	1,759	1,657	1,650	1,632	1,632
NF Clearwater (DWR)[c]	16,363	12,026	11,302	10,851	586	-1,527
Clear (DWR)[c]	5,254	3,862	3,629	3,484	986	986
Lolo wild	893	706	665	662	642	642
Lolo (DWR)[u]	619	455	428	426	413	413
Lochsa wild	1,263	997	939	935	907	907
Selway wild	2,168	1,712	1,612	1,606	1,558	1,558
SF Clearwater wild	3,144	2,483	2,338	2,329	2,165	2,165
South Fork (DWR)[u]	4,654	3,421	3,215	3,203	2,967	2,967
South Fork (DWR)[c]	12,852	9,446	8,877	8,523	-3,922	-4,122

Final dispositions are known for fish within the Clearwater River basin that enter hatchery weirs at Dworshak Fish Hatchery (North Fork Clearwater River), Kooskia Fish Hatchery (Clear Creek, a tributary to Middle Fork Clearwater River), and Crooked River (tributary to South Fork Clearwater River). Fish collected at Kooskia Fish Hatchery are typically recycled to the fishery, as are fish in excess of broodstock needs at Dworshak Hatchery. These two hatcheries operate within the Lower Clearwater population. During the 2011-2012 run, Dworshak Hatchery collected 4,633 clipped hatchery fish but released 2,585 of them (USFWS 2013). However, the estimated harvest on the Dworshak direct release group only allowed for an escapement of 586 fish. The Crooked River weir collected three hatchery fish and another 197 were collected for broodstock by angling in the South Fork Clearwater River (Stiefel et al. 2013). Estimated harvest on the South Fork Clearwater clipped stock (DWR) exceeded the number of fish in the system. However, based on unclipped hatchery fish only, 57.8% of the South Fork Clearwater spawning population was composed of hatchery fish. Unclipped hatchery fish also escaped into Lolo Creek. We estimated 39.1% of the Lolo Creek spawning population was composed of hatchery fish.

Grande Ronde River

Abundance for stocks from the Grande Ronde major population group at Bonneville Dam was 9,391 wild fish; and 19,595 for clipped hatchery release groups (Table 10). We estimated that 18.6% of the wild fish and 27.7% of the hatchery fish were lost between Bonneville and Ice Harbor dams. Within the study area, loss rates of wild and clipped hatchery Grande Ronde stocks were higher in the Snake River fisheries upstream of Lower Granite Dam (reaches 3 and 4) compared to downstream of Lower Granite. Loss rates for hatchery fish were greatest within the Grande Ronde, but for wild stocks, losses within the Grande Ronde were less than total losses in the Columbia River. Losses within the lower Snake River (reach 1) were 31 wild fish (0.4%) and 884 clipped hatchery fish (6.2%). Losses in the basin upstream of Lower

Granite Dam (reaches 3 and 4) were 62 wild fish (0.9%) and 1,927 clipped hatchery fish (14.8%). Losses within the Grande Ronde River were 329 wild fish (4.7%) and 6,486 clipped hatchery fish (58.7%). We estimated escapement in the Grande Ronde River was 6,635 wild fish and 4,566 clipped hatchery fish.

Final dispositions are known for fish within the Grande Ronde River that enter the three weirs operated within the area: Wallowa Hatchery, Big Canyon acclimation pond (tributary to the Wallowa River), and Cottonwood acclimation pond (at rkm 46 on the Grande Ronde River). There were 1,080 clipped hatchery fish removed at Cottonwood weir (J. Bumgarner, unpublished data). Data are not available for 2011-2012 for the two Wallowa weirs, but in 2010 8,149 hatchery fish were collected at these weirs (Warren et al. 2013). The return of clipped hatchery fish at Lower Granite Dam during the 2010-2011 run was 52.9% of the 2009-2010 run. Scaling by this factor means 4,311 clipped hatchery fish should have been removed. However, after allocating the estimated harvest, the model indicated a deficit of 1,203 hatchery fish. Obviously, if the hatcheries collected sufficient broodstock, then there is an error in the model, either with respect to an input value or model assumption.

Table 10. Reconstruction of wild and hatchery stocks residing in the Grande Ronde major population group. Weir take for Wallowa hatchery is based on 2010 data. Hatchery stocks are listed by release site with stock abbreviation in parentheses. Abbreviations are given in Table 1. Unclipped hatchery releases are denoted by [u] and clipped releases by [c].

	Abundance at:					
Stock	**BON**	**ICH**	**LGR**	**Grande Ronde mouth**	**Escape**	**Left to spawn**
Lower Grande Ronde wild	1,535	1,249	1,148	1,137	1,083	1,083
Joseph Creek wild	1,117	909	836	829	790	790
Cottonwood (WLH)[c]	6,263	4,523	4,144	3,529	1,458	378
Wallowa wild	3,057	2,488	2,287	2,267	2,160	2,160
Wallowa (WLH)[c]	13,332	9,644	8,835	7,523	3,108	-1,203
Upper Grande Ronde	3,682	2,997	2,755	2,731	2,602	2,602

Salmon River

Abundance for stocks from the Salmon major population group at Bonneville Dam was 17,984 wild fish; 8,459 for the unclipped hatchery releases; and 97,420 for clipped hatchery release groups (Table 11). We estimated that 24.0% of the wild fish and 22.2% of the hatchery fish were lost between Bonneville and Ice Harbor dams. Loss rates for hatchery fish were greatest within the Salmon River, but for wild and unclipped hatchery stocks, losses within the Salmon River were less than total losses in the Columbia River. Losses within the lower Snake River (reach 1) were 55 wild fish (0.4%), 27 unclipped hatchery fish (0.4%), and 4,725 clipped hatchery fish (6.2%). Losses in the Snake River upstream of Lower Granite Dam (reaches 3 and 4) were 105 wild fish (0.9%), 53 unclipped hatchery fish (0.9%), and 9,658 clipped hatchery fish (13.5%). Losses within the Salmon River were 170 wild fish (1.4%), 135 unclipped hatchery fish

(2.2%), and 32,548 clipped hatchery fish (52.7%). We estimated escapement in the Salmon River was 11,839 wild fish, 6,009 unclipped hatchery fish, and 29,159 clipped hatchery fish.

Table 11. Reconstruction of wild and hatchery stocks residing in the Salmon River major population group. Hatchery stocks are listed by release site with stock abbreviation in parentheses. Abbreviations are given in Table 1. Unclipped hatchery releases are denoted by [u] and clipped releases by [c].

	Abundance at:					
Stock	**BON**	**ICH**	**LGR**	**Salmon River**	**Escape**	**Left to spawn**
Little Salmon wild	1,786	1,357	1,203	1,192	1,175	1,175
Little Salmon (PAH)[u]	1,516	1,179	1,111	1,102	1,075	1,075
Little Salmon (PAH,OX,DWR)[c]	18,834	14,646	13,797	11,930	7,114	7,114
South Fork Salmon wild	1,021	776	688	682	679	679
Secesh wild	437	332	294	292	292	292
Chamberlain Creek wild	609	463	410	406	402	402
Lower Middle Fork wild	1,707	1,297	1,150	1,140	1,131	1,131
Upper Middle Fork wild	1,818	1,382	1,225	1,214	1,203	1,203
Panther Creek wild	774	588	521	517	510	510
North Fork Salmon wild	442	336	298	296	293	293
Lemhi wild	2,486	1,889	1,674	1,659	1,636	1,636
Salmon, sec 19 (PAH)[c]	2,913	2,265	2,134	1,845	1,058	1,058
Pahsimeroi wild	2,061	1,566	1,388	1,376	1,353	1,353
Salmon, sec 20 (USB)[u]	215	167	157	155	154	49
Salmon, sec20 (PAH)[c]	38,462	29,908	28,175	24,363	12,660	4,744
East Fork Salmon wild	2,192	1,666	1,477	1,464	1,439	1,367
East Fork (EFN)[u]	2,645	2,057	1,938	1,921	1,886	1,848
Salmon, sec 21 (SAW,DWR)[c]	7,051	5,483	5,165	4,466	2,142	2,138
Upper Salmon wild	2,651	2,015	1,786	1,771	1,726	1,726
Salmon, sec 22 (SAW)[u]	4,083	3,175	2,991	2,966	2,894	1,540
Salmon, sec 22 (SAW,USB,DWR)[c]	30,160	23,453	22,094	19,103	6,185	3,286

Final dispositions are known for fish within the Salmon River that enter the four weirs operated within the area: Pahsimeroi Hatchery, East Fork Salmon weir, Squaw Creek weir, and Sawtooth Hatchery (Stiefel et al. 2013). The latter two traps operate within the Upper Salmon population. In 2012, 7,916 clipped hatchery fish were removed by the Pahsimeroi Hatchery. Subtracting these fish leaves 78.0% of the Pahsimeroi spawning population composed of hatchery fish. Hatchery steelhead at large are assumed to remain in the main-stem Salmon River between the Lemhi and the Pahsimeroi rivers or stray into minor tributaries to that reach. At the East Fork Salmon weir, removals were 72 wild fish, 38 unclipped hatchery fish, and four clipped hatchery fish. Subtracting these fish leaves 74.3% of the East Fork Salmon spawning population composed of hatchery fish, most of which (53.6%) were clipped fish from a segregated broodstock. At the two Upper Salmon weirs, a total of 4,251 hatchery fish were removed, although it was not recorded how many were clipped versus unclipped. We apportioned these fish according to the relative escapements of the two groups. Subtracting these fish leaves 73.7% of the Upper Salmon spawning population composed of hatchery fish.

Hatchery fish also escaped into the Lemhi population (39.3% of the potential spawners) and Little Salmon population (87.5% of the potential spawners). In the Little Salmon River, 86.7% of the hatchery escapement was composed of clipped hatchery fish. Realized hatchery impacts are uncertain and may not be proportional to fish numbers in some populations because hatchery steelhead release sites are some distance from spawning tributaries.

Imnaha River

Abundance for stocks from the Imnaha major population group at Bonneville Dam was 3,128 wild fish and 4,611 for clipped hatchery fish. We estimated that 573 wild fish (18.3%) and 1,100 hatchery fish (23.9%) were lost between Bonneville and Ice Harbor dams. Losses within the lower Snake River (reach 1) were 10 wild fish (0.4%) and 219 clipped hatchery fish (6.2%). Losses in the Snake River upstream of Lower Granite Dam (reaches 3 and 4) were 23 wild fish (1.0%) and 643 clipped hatchery fish (19.8%). Losses within the Imnaha were 207 wild fish (9.0%) and 403 clipped hatchery fish (15.5%). We estimated escapement in the Imnaha River was 2,099 wild fish and 2,196 clipped hatchery fish.

Final dispositions are known for fish within the Imnaha River that enter the Little Sheep Creek weir. Data are not available for 2011-2012 but in 2010 3,450 hatchery fish were collected at the weir (E. Sedell, unpublished data). Scaling this number as done in the Wallowa River means 1,824 clipped hatchery fish should have been removed. We estimate there were 372 clipped hatchery fish and 2,099 wild fish left to potentially spawn in the habitat; 15.1% of the potential spawners in the Imnaha River were comprised of hatchery fish.

Hells Canyon

Abundance at Bonneville Dam for hatchery fish released in Hells Canyon was 26,069 fish. We estimated that 7,296 fish (28.0%) were lost between Bonneville and Ice Harbor dams. Losses within the lower Snake River (reach 1) were 1,171 fish (6.2%). Losses in the Snake River upstream of Lower Granite Dam (reaches 3 and 4) were 2,998 fish (17.2%) and 4,759 fish within Hells Canyon (reach 24). Loss rate within Hells Canyon of clipped hatchery fish was 32.5%. Catch data suggest that 19 unclipped fish likely died after release. We estimated escapement in Hells Canyon was 9,881 clipped hatchery fish.

Final dispositions are known for fish that enter the Hells Canyon Dam fish trap (Stiefel et al. 2013). For the 2011-2012 run, this trap collected 107 unclipped fish and 3,767 adipose-clipped hatchery fish. Subtracting these fish leaves 6,007 steelhead left to potentially spawn. We estimate that 41.8% of the hatchery return to Hells Canyon were not accounted for by harvest impacts and were available to spawn or die within the population area. If we assume that the wild-to-hatchery ratio in the habitat is the same as at the Hells Canyon trap, then 97.2% of the spawning population is composed of escaping hatchery fish.

DISCUSSION

This run reconstruction is our second effort to synthesize data for all wild populations and hatchery stocks across the Snake River basin. We attempted to quantify the fishery-related impacts on steelhead as they move to their natal or release areas. In doing so, we summarized effects on natural populations and highlighted the benefits of hatchery programs. Efforts focused on compilation of data with general assumptions that may limit specific conclusions; however, the resulting analytical framework can be refined for more rigorous evaluations in the future. In the following discussion, we review changes to model structure from the inaugural effort, compare selected results to independent data to assess model performance, and suggest how the run reconstruction model may be improved. We close with several observations to consider for future work.

Model changes

The first change made was adjustment of the estimates of fish crossing Lower Granite Dam; that is, increasing the counts of all categories to account for nighttime passage and decreasing stock-specific counts to account for double-counting of fish re-ascending the ladder. These two adjustments effectively cancelled each other out because the resulting adjusted total was 99.7% of the window count (all stocks and origins). However, the adjustments had the important stock-specific effect of reducing the numbers of wild fish in the Asotin and Tucannon populations. For all Lower Snake stocks, abundance at Lower Granite Dam was reduced by 20.2%. Because these stocks tend to re-ascend the ladder at higher rates than other stocks, they are disproportionately represented in the samples collected for genetic stock assignments. Adjusting for re-ascension thus corrects this sampling bias. Effect on other stocks was negligible; the adjustments increased estimates of the upriver stocks by 1.2%.

There is some concern that our treatment of the abundance estimate at Lower Granite Dam departs from past practices (e.g., by the Technical Advisory Committee for the *US v. Oregon* management agreement). We made adjustments to address concerns specific to our objective to estimate the disposition of steelhead within the Snake River basin. The unadjusted counts produced unsatisfactory results for lower Snake stocks in the 2010-2011 run (Copeland et al. 2013). The level of detail in this run reconstruction is smaller than has been considered before. Because we are attempting to account for fates at a much finer grain, biases regarding stock-specific behavior at Lower Granite Dam become important enough to include in the model. Treatment of the data depends on the specific question and application. We do not advocate for an across-the-board adjustment of the Lower Granite abundance estimate that has been used historically to assess trends in the Snake River steelhead DPS. Any adjustments must be made on a case-by-case basis and should not be construed as universally applicable.

The second change was the inclusion of stock-specific stray rates in the Clearwater River based on coded wire tag recoveries in the fishery. In the first effort, we used a rate of 6.0% based on expert opinion and applied this to fish moving past the lower Clearwater reach and the North Fork Clearwater. The overall averages were very close to 6% but the coded wire tag recoveries showed that the rate could vary widely for stocks going by the lower Clearwater River. Both model changes follow our guideline that changes must be relevant to management and supported by data.

Comparison to independent data

We compiled selected data to evaluate escapement estimates for wild steelhead (Table 12). These data were population estimates based on weir counts, PIT array detections in spawning streams, and redd count expansions. The coverage of most of these independent estimates was smaller than the population level, so we used relative amount of weighted intrinsic spawning habitat potential to scale our escapement estimates to the independent data. In a few cases, the scale of the independent estimate was less than a defined spawning aggregate, so we estimated the proportion of habitat captured by the independent estimate within the spawning aggregate from the maps in the 2010 steelhead status assessment (Ford et al. 2010). The Imnaha and Tucannon PIT arrays are near the river mouth, so we used the pre-fishery abundance estimate.

Table 12. Comparison of run reconstruction wild steelhead escapements scaled by spawning habitat intrinsic potential to independent population estimates. Asterisks indicate units smaller or larger than populations of the same name. Confidence intervals are in parentheses.

Scaled model prediction		**Independent data**		
Unit	**Estimate**	**Estimate**	**Type**	**Source**
Tucannon*	4,231	115	PIT array	JDB, unpublished data
Tucannon*	1,056	186	Weir count	JDB, unpublished data
Asotin Creek*	2,743	1,253	Weir count	JDB, unpublished data
Lolo Creek	642	680 (520-840)	PIT array	QCI 2013
Fish Creek	100	152 (126-183)	Weir estimate	Copeland et al. 2013
SF Clearwater	2,164	1,201 (977-1,425)	PIT array	QCI 2013
Joseph Creek	792	1,357 (977-1,736)	Redd estimate	Jonasson et al. 2013
Joseph Creek	792	1,974 (1,664-2,284)	PIT array	QCI 2013
Upper Grande Ronde	2,608	3,260 (2,184-4,336)	Redd estimate	Jonasson et al. 2013
South Fork Salmon*	971	1,510 (1,244-1,776)	PIT array	QCI 2013
Secesh	292	202 (107-297)	PIT array	QCI 2013
Big Creek	449	490 (154-826)	PIT array	QCI 2013
Lemhi*	1,584	421 (272-570)	PIT array	QCI 2013
Pahsimeroi*	1,149	288	Weir count	Stiefel et al. 2013
East Fork Salmon*	169	94	Weir count	Stiefel et al. 2013
Valley Creek	244	290 (188-392)	PIT array	QCI 2013
Upper Salmon*	612	63	Weir count	Stiefel et al. 2013
Imnaha	2,306	2,984 (2,750-3,218)	PIT array	QCI 2013
Cow Creek	24	131 (59-203)	PIT array	QCI 2013
Big Sheep Creek	407	901 (707-1,095)	PIT array	QCI 2013

The run reconstruction escapements for wild populations were less than independent estimates in 11 cases and greater in 9 cases. The average magnitude of the overestimates was greater than for underestimates (6.5 versus 0.4 as the proportion of the independent estimate). The greatest departures were between estimates involving populations within the Lower Snake genetic reporting group. The run reconstruction estimates of this group likely include out-of-basin strays, which is consistent with estimates larger than independent data. Other large overestimates came from populations within the Upper Salmon genetic reporting group.

In some cases, run reconstruction escapements were consistent with expectations. The Big Creek and Lolo Creek estimates were within 10% of the independent estimates. For estimates with confidence intervals, five of 14 model predictions were within the confidence intervals. However, there is much unresolved variation among estimates of most wild populations. Some of this is related to genetic similarity among stocks and some is related to the use of the intrinsic potential habitat index as a metric of relative population density.

For hatchery stocks, there were several instances where the model predicted a negative escapement or fewer fish than were collected at weirs in the reach: in the Tucannon, Clearwater, and Grande Ronde rivers. These instances only concerned fish subject to sport fisheries because predicted escapements for unclipped hatchery fish returning to an area with a weir were all above numbers actually collected. There are three possible explanations: 1) non-Snake origin fish were present that are not in the model, or 2) abundance estimates were too low, or 3) harvest estimates were too high.

We address the first explanation concerning non-Snake steelhead. Clipped steelhead from Umatilla River releases were detected crossing Ice Harbor Dam (JB, unpublished data); however, none crossed Lower Granite Dam or were detected at the Tucannon array. The preliminary expansion estimate was 101 fish from these stocks. Adding these fish into the Lower Snake fishery did not result in any more fish entering the Tucannon River. The other non-Snake stocks detected were already in the model (Walla Walla River releases).

Second, we consider how the independent abundance estimates could be underestimated. In the Tucannon, numbers of fish are estimated based on the PIT array near the mouth. If array efficiency is not incorporated, then number of fish entering from the Lower Snake based on PIT detections will be low. We note that the number collected at the weir is greater than expanded number of wild fish crossing the array, so this is likely. If this ratio is used to adjust model estimates of fish at the river mouth, then enough fish enter to explain the discrepancies. Discrepancies in the other rivers cannot be explained this way (in total a 6,852 fish deficit for stocks in the Grande Ronde and Clearwater rivers). These stocks could be under-represented in the PIT expansions generating their initial abundance. Again, we note that expansion of unclipped hatchery stocks appear to work well in the model. Hence, the discrepancies cannot be explained only by false assignments, except in a minor way.

Another explanation for the discrepancies is that harvest was overestimated. Fisheries operations have been over-simplified in the model but there will be discrepancies to abundance no matter how harvest is treated. Creel-based estimates can be biased for a number of reasons (Lockwood 1997; Rasmussen et al. 1998). Flesher et al. (2012) observed that harvest estimates based on post-season tag returns were usually biased higher than those derived from in-season creel surveys. Comparing the 2010/2011 run to the 2011/2012 run shows that abundance of steelhead declined while angler effort increased. This scenario would have the effect of aggravating any biases in the input data.

Improvements to the model

Our immediate objective was to develop an analytical run reconstruction framework that could be refined for more rigorous evaluations in the future. The initial version was necessarily simplistic and there are several modifications that might be reasonable. However, changes should influence results in some substantial manner, otherwise those factors may be safely ignored for the sake of parsimony. As a general guideline, further elaborations need to be relevant to management and supported by data. Below are some ideas that might be explored.

Methods for parsing abundance of wild fish need further investigation and refinement. Although not formally within the run reconstruction model, genetic stock identification is a primary input. This is further modified by the intrinsic potential habitat index to estimate abundance at the populations delineated by the ICBTRT (2003). Both components need critical evaluation. We recommend an evaluation of methods to distinguish mid-Columbia steelhead stocks so that we may account for out-of-basin strays. Correction factors need to be developed to accommodate for out-of-basin fish that assigned to Snake River stocks, especially the Lower Snake MPG (Tucannon and Asotin populations), where the model estimate is many times higher than independent estimates. The habitat index is likely useful at very large spatial scales but will be increasingly imprecise as scale declines below the population level (Tom Cooney, personal communication).

Fisheries were assumed to operate in a very simplified way in the current model. To achieve a more accurate assignment of harvest impacts, a time element may need to be incorporated. Component stocks in mixed stock fisheries could have differential fishery vulnerability (Starr and Hilborn 1988), e.g., in the Lower Snake fishery reach. Addition of a time component to the model would require better harvest and movement estimates. Biases are inherent in the use of tag recoveries to infer movement probabilities. These biases need to be identified and addressed. More realistic movement rules may be desirable in any case (e.g., to address fallback rates at Lower Granite Dam).

The fates of Snake River steelhead downstream of the study area are vague in this model. Beginning in 2008, parentage-based tagging (PBT) has been used to genetically tag nearly all hatchery-origin steelhead in the Snake River basin (Steele et al. 2013). However, not all groups are tracked to a release point, which would be necessary to include them in the model. Nonetheless, Byrne et al. (*in prep*.) have conducted analyses of steelhead harvested in fisheries between Bonneville and McNary dams and in the sport fishery between Bonneville Dam and the river mouth. Once we can resolve their data with the requirements of the model, we will be able to apportion losses between Bonneville and McNary dams into fishery- and non-fishery sources. Further, we will be able to reconstruct runs of clipped Snake River steelhead all the way downstream to the ocean by accounting for harvest in the recreational fishery downstream of Bonneville Dam. By adapting the methods of Conrad et al. (2013) relating the exploitation rates of marked and unmarked fish in selective fisheries, we may be able to extend impacts on unclipped fish to the river mouth as well.

Only fishery-related mortality was considered in the current run reconstruction model. Unlike most of the run reconstruction models reported in the literature (e.g., Bue et al. 2012, Cunningham et al. 2012), this model focuses on steelhead stocks that migrate far inland and spend a significant amount of time in freshwater during fisheries and before spawning. Therefore, natural mortality may be important. The current model structure can accommodate estimates of natural mortality if the data exist with which to compute them.

At some point, model behavior and performance needs to be assessed with a sensitivity analysis. Understanding model behavior is crucial to understanding whether the model has potential to provide useful insights into the real world (McElhany et al. 2010). Such analyses test the degree to which input data or model parameters affect the output (Steel et al. 2009). This would require some measure of uncertainty about the relevant values (e.g., variance of harvest estimates) but this could be developed from expert opinion, e.g., in the form of a uniform distribution of a mean with some percentage error (McElhany et al. 2010). The purpose would be to refine model structure and define the scope for advice to managers.

Lastly, in the current model it is assumed that the steelhead life cycle ends at spawning. It does not (Withler 1961; Busby et al. 1996). Post-spawn steelhead (kelts) represent a disposition category that exits the spawning reach and emigrates to the ocean. There are several efforts to collect data on kelts with the thought that repeat-spawning steelhead can provide demographic benefits. Colotelo et al. (2013) estimated 40,578 kelts emigrated past Lower Granite Dam in 2012. This value is likely biased high because it is based on tags placed in only five locations. However, we estimate that 68,483 fish remained in natural habitats to spawn, which corresponds to a 59% kelt rate if using the Colotelo et al. kelt estimate. This kelt rate is reasonable but will vary by population because distance and timing of spawn will affect probability of surviving to Lower Granite Dam as a kelt. Penney and Moffitt (2014) found much variability in kelt condition, which will limit post-spawning survival. The factors that cause a fish to be in good, fair, or poor condition are certainly variable between individuals, spawning years, and locations.

Other considerations

One of the important assumptions made in the model is that, within mark type, fishery mortality affects fish in proportion to their abundance (Copeland et al. 2013). In the Lower Snake, fishery losses explain 98.5% of conversion losses of clipped fish from stocks upstream of Lower Granite Dam. Thus, model predictions compare well and support assumption of proportional assignment of mortality for this fishery. It is tempting to think that the estimates of main stem harvest levels are reasonable and note that some characteristic of terminal fisheries biases estimates in those areas upwards. However, estimated fishery impacts on unclipped upriver stocks explain only 4.9% of the conversion losses between Ice Harbor and Lower Granite dams. These unexplained losses bear consideration in the future.

We observed that the Columbia River (Bonneville Dam to Ice Harbor Dam) was the area of greatest loss for wild and unclipped hatchery fish. Of the unclipped steelhead crossing Bonneville Dam, 22.5% did not make it to Ice Harbor Dam. These are fish protected under ESA (wild) or meant to supplement wild populations. In comparison, of the clipped hatchery fish meant to mitigate for harvest losses, 24.4% of those crossing Bonneville Dam did not make it to Ice Harbor Dam. The similarity of these loss rates should be of concern for the conservation and restoration of wild steelhead in the Snake River.

We have concerns with our attempts to parse out the wild steelhead populations in the Lower Snake genetic group and the continued mismatch between weir counts and our model estimates. As yet, we have not succeeded at estimating fates of those stocks with confidence. As discussed earlier, we could adjust the abundance of the Lower Snake group if we could account for out-of-basin strays. The attempts to use PIT detections to estimate movements in the lower Snake reach were simplistic and may be improved with careful thought. Modelling lower Snake steelhead has a unique set of challenges not present for the upriver stocks. New sources of data (e.g., telemetry) may be necessary if it is important to know something about them.

SUMMARY

We have developed a tool for comparative use by steelhead managers in the Snake River basin. This work provides a useful framework for synthesizing data collected by fisheries managers that allows inferences regarding disposition and spatial distribution of spawning fish. The run reconstruction process is a good arena for critical review of the data that managers in the basin use. For example, in this report, we found inconsistencies between abundance and harvest of clipped hatchery stock. The model can be used to bridge gaps in the existing data using reasonable assumptions in a structured manner. The resulting output will help evaluate the performance of the Snake River steelhead evolutionarily significant unit (ESU) and hatchery programs towards management goals and ESA delisting criteria. Future improvements will improve precision and accuracy.

REFERENCES

Ackerman, M. W., and M. R. Campbell. 2012. Chinook and steelhead genotyping for genetic stock identification at Lower Granite Dam. BPA project 2010-026-00. Idaho Department of Fish and Game report 12-15. Boise.

Boggs, C. T., M. L. Keefer, C. A. Peery, T. C. Bjornn, and L. C. Stuehrenberg. 2004. Fallback, reascension, and adjusted fishway escapement estimates for adult Chinook salmon and steelhead at Columbia and Snake river dams. Transactions of the American Fisheries Society 133:932-949.

Brandt, S. 2009. 2009 Snake River steelhead monitor and evaluation of harvest. Shoshone Bannock Tribes, Fort Hall, Idaho.

Bue, B. G., K. L. Schaberg, Z. W. Liller, and D. B. Molyneaux. 2012. Estimates of the historic run and escapement for the Chinook salmon stock returning to the Kuskokwim River, 1976-2011. Alaska Department of Fish and Game, Fishery Data Series No. 12-49. Anchorage.

Bumgarner, J. D., and J. Dedloff. 2011. Lyons Ferry Complex Hatchery evaluation: summer steelhead annual report 2008 and 2009 run years. Report to U.S. Fish and Wildlife Service, Lower Snake River Compensation Plan Office, Boise, Idaho. FPA 11-05.

Busby, P. J., T. C. Wainwright, G. J. Bryant, L. J. Lierheimer, R. S. Waples, F. W. Wauneta, and I. V. Lagomarsino. 1996. Status review of West Coast steelhead from Washington, Idaho, Oregon, and California. NOAA Technical Memorandum NMFS-NWFSC-27.

Chasco, B., R. Hilborn, and A. E. Punt. 2007. Run reconstruction of mixed-stock salmon fisheries using age-composition data. Canadian Journal of Fisheries and Aquatic Sciences. 64:1479-1490.

Colotelo, A. H., B. W. Jones, R. A. Harnish, G. A. McMichael, K. D. Ham, Z. D. Zeng, G. M. Squeochs, R. S. Brown, M. A. Weiland, G. R. Ploskey, X. Li, and T. Fu. 2013. Passage distribution and Federal Columbia River power system survival for steelhead kelts tagged above and at Lower Granite Dam. Prepared for the US Army Corps of Engineers, Walla Walla District. Contract W912EF-08-D-0004. Battelle Pacific Northwest Division, Richland, Washington.

Conrad, R., A. Hagen-Breaux, and H. Yuen. 2013. Unbiased methods for calculating mortality in mark-selective fisheries models for ocean salmon. North American Journal of Fisheries Management 33:253-264.

Copeland, T., J. Bumgarner, A. Byrne, L. Denny, J. L. Hebdon, M. Johnson, C. A. Peery, S. Rosenberger, E. R. Sedell, G. E. Shippentower, C. Stiefel, and S. P. Yundt. 2013. Reconstruction of the 2010/2011 steelhead spawning run into the Snake River basin. Report to Bonneville Power Administration, Portland, Oregon.

Cunningham, C. J., R. Hilborn, J. Seeb, M. Smith, and T. Branch. 2012. Reconstruction of Bristol Bay sockeye salmon returns using age and genetic composition of catch. SAFS-UW-1202. University of Washington, Seattle.

Dauble, D. D., and R. P. Mueller. 2000. Upstream passage monitoring: difficulties in estimating survival for adult Chinook salmon in the Columbia and Snake rivers. Fisheries 25(8):24-34.

Flesher, M. W., R. W. Carmichael, and L. R. Clarke. 2012. Summer steelhead creel surveys on the Grande Ronde, Wallowa, and Imnaha rivers for the 2009-10 run year. Report to the US Fish and Wildlife Service, Lower Snake River Compensation Plan. Contract 1411-A-J010. Oregon Department of Fish and Wildlife, Salem.

Ford, M., T. Cooney, P. McElhany, N. Sands, L. Weitkamp, J. Hard, M. McClure, R. Kope, J. Myers, A. Albaugh, K. Barnas, D. Teel, P. Moran, and J. Cowen. 2010. Status review update for Pacific salmon and steelhead listed under the Endangered Species Act: Northwest. Draft US Department of Commerce, NOAA Technical Memorandum NOAA-TM-NWFSC-XXX.

Fryer, J. K., J. Whiteaker, and D. Kelsey. 2012. Upstream migration timing of Columbia Basin Chinook and sockeye salmon and steelhead in 2010. Columbia River Inter-Tribal Fish Commission Technical Report 12-02. Portland, Oregon.

(ICBTRT) Interior Columbia Basin Technical Recovery Team. 2003. Independent populations of Chinook, steelhead, and sockeye for listed Evolutionarily Significant Units within the interior Columbia River domain. Northwest Fisheries Science Center. Seattle, Washington. Available: http://www.nwfsc.noaa.gov/trt/col/trt_pop_id.cfm.

(ICBTRT) Interior Columbia Basin Technical Recovery Team. 2007. Viability criteria for application to Interior Columbia Basin salmonid ESUs. Northwest Fisheries Science Center. Seattle, Washington. Available: http://www.nwfsc.noaa.gov/trt/col/trt_viability.cfm.

Jonasson, B. C., S. D. Favrot, C. D. Horn, M. E. Dobos, E. R. Sedell, J. M. Whitty, A. B. Garner, M. P. Ticus, J. R. Ruzycki, K. Bliesner, and R. W. Carmichael. 2013. Investigations into the life history of naturally produced spring Chinook Salmon and summer steelhead in the Grande Ronde River Subbasin, 1/1/2012-12/31/2012 annual report to the US Department of Energy, Bonneville Power Administration. Project 1992-026-04. Oregon Department of Fish and Wildlife, Salem.

Lockwood, R. N. 1997. Evaluation of catch rate estimators from Michigan access point angler surveys. North American Journal of Fisheries Management 17:611-620.

Mallet, J. 1974. Inventory of salmon and steelhead resources, habitat, use and demands. Job performance report. Project F-58-R-1. Idaho Department of Fish and Game, Boise.

McElhany, P., E. A. Steel, K. Avery, N. Yoder, C. Busack, and B. Thompson. 2010. Dealing with uncertainty in ecosystem models: lessons from a complex salmon model. Ecological Applications 20:465-482.

Penney, Z. L., and C. M. Moffitt. 2014. Proximate composition and energy density of stream-maturing adult steelhead during upstream migration, sexual maturity, and kelt emigration. Transactions of the American Fisheries Society 143:399-413.

Petrosky, C. E. 2012. 2011 annual report to NOAA Fisheries, fishery management and evaluation plans 4(d) rule limit 4: the incidental take of ESA listed salmon and steelhead during conduct of recreational fisheries in Idaho. Idaho Department of Fish and Game, Boise.

QCI (Quantitative Consultants Incorporated). 2013. Integrated Status and Effectiveness Monitoring Project: Salmon subbasin annual report, 2012. Bonneville Power project 2003-017-00.

Quinn, T. J., and R. B. Deriso. 1999. Quantitative Fish Dynamics. Oxford University Press. New York.

Rasmussen, P. W., M. D. Staggs, T. D. Beard, and S. P. Newman. 1998. Bias and confidence interval coverage of creel survey estimators evaluated by simulation. Transaction of the American Fisheries Society 127:469-480.

Schrader, W. C., T. Copeland, P. Kennedy, M. W. Ackerman, K. K. Wright, and M. R. Campbell. 2012. Wild adult steelhead and Chinook salmon abundance and composition at Lower Granite Dam, spawn year 2010. Annual report 2010, BPA Projects 1990-055-00, 1991-073-00, 2010-026-00. Idaho Department of Fish and Game Report 12-16. Idaho Department of Fish and Game, Boise.

Schrader, W. C., M. P. Corsi, P. Kennedy, M. W. Ackerman, M. R. Campbell, K. K. Wright, and T. Copeland. 2013. Wild adult steelhead and Chinook salmon abundance and composition at Lower Granite Dam, spawn year 2011. Idaho Department of Fish and Game Report 13-15. Annual report 2011, BPA Projects 1990-055-00, 1991-073-00, 2010-026-00.

Starr, P., and R. Hilborn. 1988. Reconstruction of harvest rates and stock contribution in gauntlet salmon fisheries: application to British Columbia and Washington sockeye (*Oncorhynchus nerka*). Canadian Journal of Fisheries and Aquatic Sciences 45:2216-2229.

Steel, E. A., P. McElhany, N. J. Yoder, M. D. Purser, K. Malone, B. E. Thompson, K. A. Avery, D. Jensen, G. Blair, C. Busack, M. D. Bowen, J. Hubble, and T. Kantz. 2009. Making the best use of modeled data: multiple approaches to sensitivity analyses of a fish-habitat model. Fisheries 34:330-339.

Steele, C., J. McCane, M. Ackerman, M. Campbell, M. Hess, and S. Narum. 2013. Parentage based tagging of Snake River hatchery steelhead and Chinook Salmon. Idaho Department of Fish and Game Report 13-23. Idaho Department of Fish and Game, Boise.

Stiefel, C., S. Rosenberger, and F. Bohlen. 2013. 2012 calendar year hatchery steelhead report: IPC and LSRCP monitoring and evaluation programs for the State of Idaho. Idaho Department of Fish and Game Report 13-05. Idaho Department of Fish and Game, Boise.

USFWS (US Fish and Wildlife Service). 2013. Annual report for Dworshak National Fish Hatchery, fiscal year 2012.

Warren, S. M., M. W. Flesher, D. L. Eddy, L. R. Clarke, and R. W. Carmichael. 2013. Lower Snake River Compensation Plan: Oregon summer steelhead evaluation studies, 2011 annual progress report. Oregon Department of Fish and Wildlife, Salem.

WDFW (Washington Department of Fish and Wildlife). 2009. Fisheries management and evaluation plan for recreational fisheries for summer steelhead, warmwater fish, sturgeon, carp, and other species in the Snake River basin. Washington Department of Fish and Wildlife, Olympia.

Withler, I. L. 1961. Variability in life-history characteristics of steelhead trout (Salmo gairdneri) along the Pacific Coast of North America. Masters thesis. University of British Columbia.